2.8.8. T1 Repeater Spacing Parameters

Definition: Minimum design separation, measured in decibels, on copper cable as a function of the maximum loss between adjacent repeaters at 772 kHz, and the loss of the copper cable on which the repeaters are installed. Used for T1 carrier long loop extensions.

Default Values:

dB Loss at 772 kHz		
Maximum dB Loss Between T1 Repeaters	dB Loss per 1,000 ft. of Aerial Air Core PIC Distribution Cable	dB Loss per 1,000 ft. of Buried & Underground Filled Solid PIC Cable
32.0	6.3	5.0

Support: Since these conditions occur on extremely long and small distribution cables, and since the HAI Model assumes 24 gauge cable for cable sizes of less than 400 pairs, the model assumes 24 gauge copper cable for these circuits. Although a maximum of 35 dB between T1 repeaters has been noted in the literature[12], a conservative value of 32.0 dB is recommended for the HAI Model default. T1 circuits are normally designed at the 772 kHz frequency point. Copper cable attenuation at this frequency is a function of the type of cable and the temperature of operation. The higher the temperature, the greater the attenuation.

Aerial cable is normally air core PIC (Plastic Insulated Conductor) cable. At the highest envisioned temperature of 140 degrees Fahrenheit, the attenuation is 6.3 dB/kft.[13]

Buried and Underground cable is normally considered to operate within normal temperature ranges. The HAI Model default values assume cables are filled with water blocking compound, using solid PIC insulation. The attenuation for such cable is 5.0 dB/kft.[14]

2.9. SAI INVESTMENT

Definition: The installed investment in the Serving Area Interface (SAI) that acts as the physical interface point between distribution and feeder cable.

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[12] Roger L. Freeman, *Reference Manual for Telecommunications Engineering – Second Edition*, p.574-575.

[13] Lucent, *Outside Plant Engineering Handbook*, 1996, p. 5-14.

[14] Lucent, *Outside Plant Engineering Handbook*, 1996, p. 5-15.

Default Values:

SAI Investment		
SAI Size	**Indoor SAI**	**Outdoor SAI**
7200	$9,656	$10,000
5400	$7,392	$8,200
3600	$4,928	$6,000
2400	$3,352	$4,300
1800	$2,464	$3,400
1200	$1,776	$2,400
900	$1,232	$1,900
600	$888	$1,400
400	$592	$1,000
200	$296	$600
100	$148	$350
50	$98	$250

Support: Indoor Serving Area Interfaces are used in buildings, and consist of simple terminations, or punch down blocks, and lightning protection where required. Equipment is normally mounted on a plywood backboard in common space. Outdoor Serving Area Interfaces are more expensive, requiring steel cabinets that protect the cross connection terminations from the direct effects of water. Both indoor and outdoor SAI investments are a function of the total number of pairs, both Feeder and Distribution, that the SAI terminates.

The total number of pairs terminated in the SAI is computed as follows. a) The number of Feeder Pair terminations provided is equal to 1.5 times the number of households plus the number of business, special access, and public lines required. b) The number of Distribution Pair terminations provided is equal to 2.0 time the number of households plus the number of business, special access, and public lines required.

Indoor SAI investments include the cost of over-voltage protection. Costs for that protection are assumed to be based on splicing protector equipment on feeder pairs at a cost of $200 per 100 pair protector. SAIs with fewer than 200 feeder pairs are priced accordingly at $50 per 25 pair protector.

Prices are the opinion of a group of engineering experts.

Indoor SAI Investment
(without protectors)

Outdoor SAI Investment
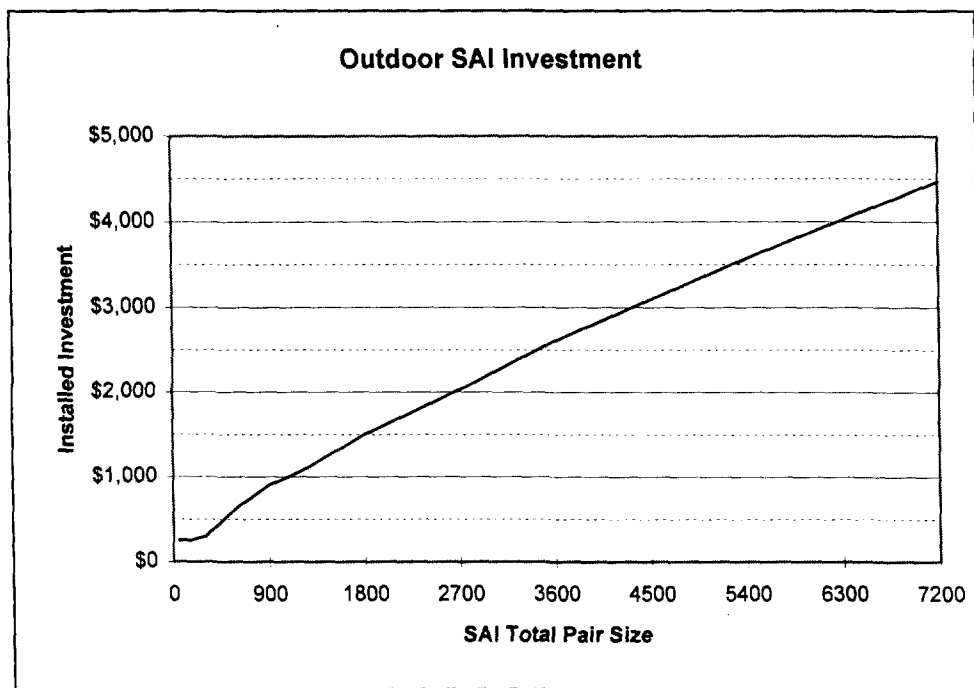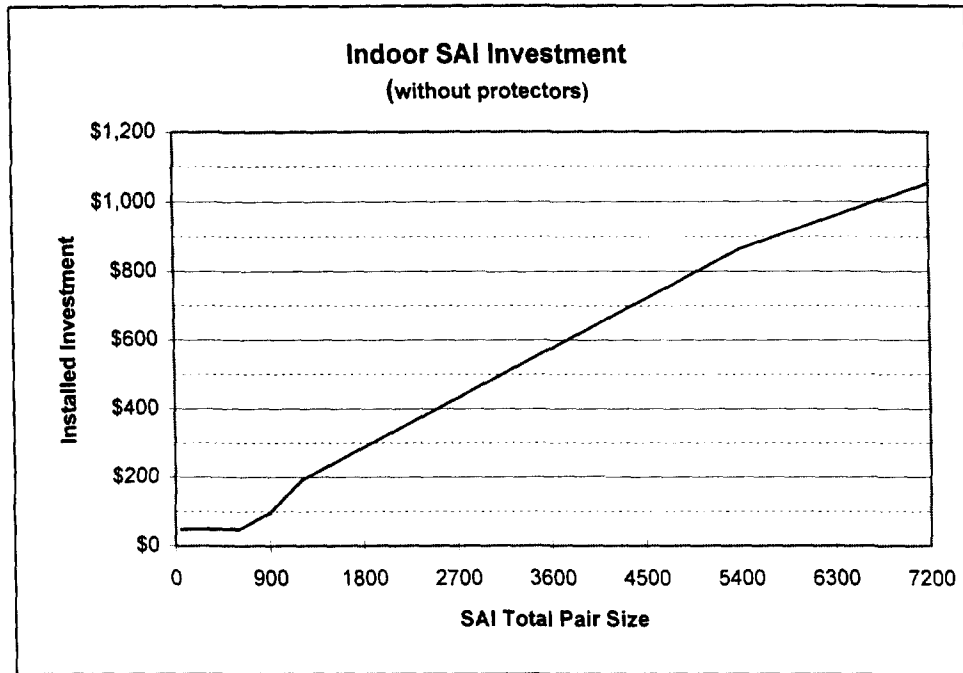
2.10. DEDICATED CIRCUIT INPUTS

2.10.1. Percentage of Dedicated Circuits

Definition: The fractions of total circuits included in the count of total private line and special access circuits that are DS-0 and DS-1 circuits, respectively. The fraction of DS-3 and higher capacity circuits is calculated by the model as (1 - fraction DS0 - fraction DS-1). The equivalence between the three circuit types -- that is, DS-0, DS-1, and DS-3 -- and wire pairs is expressed in Section 2.10.2.

Default Values:

Percentage of Dedicated Circuits	
DS-0	DS-1
100%	0%

Support: These parameters provide the breakdown of reported dedicated circuits into voice-grade equivalents and DS-0s, DS-1s, and DS-3s. The default database values for dedicated circuits represent special access voice-grade and DS-0 equivalents as reported in ARMIS 43-08. Thus, the default input values are 100 percent for DS-0/voice grade, and 0 percent for DS-1 and DS-3.

2.10.2. Pairs per Dedicated Circuit

Definition: Factor expressing the number of wire pairs required per dedicated circuit classification.

Default Values:

Pairs per Dedicated Circuit		
DS-0	DS-1	DS-3
1	2	56

Support: A DS-1 bit stream on copper requires one transmit pair and one receive pair. Although a DS-3 signal can only be transmitted on fiber or coax, the bit stream carries the equivalent of 28 DS-1's. Since a DS-1 requires 2 pairs, a DS-3 is represented in HM 5.0a as requiring 28 times 2 pairs, or a total of 56 pairs. While many DS-0s are provided on 4-wire circuits, the model conservatively assumes only one pair per DS-0.

2.11. WIRELESS INVESTMENT INPUTS

2.11.1. Wireless Investment Cap Enable

Definition: When enabled, invokes wireless investment cap for distribution plant investment calculations. In the default mode, the model does not impose the wireless cap.

Default Value:

Wireless Investment Cap Enable
Disabled

Support: If a viable wireless technology exists using forward looking, currently deployable technology, with available frequency spectrum allocation, then this alternative may be used to cap distribution costs at a pre-determined investment cost.

2.11.2. Wireless Point to Point Investment Cap – Distribution

Definition: Per-subscriber investment for hypothetical point to point subscriber radio equipment..

Default Value:

Wireless Point to Point Investment Cap
$7,500

Support: Based on HAI judgment of potential cost of such a system.

2.11.3. Wireless Common Investment

Definition: Base Station Equipment investment for hypothetical broadcast wireless loop system

Default Value:

Wireless Common Investment
$112,500

Support: Based on HAI judgment of potential cost of such a system.

2.11.4. Wireless per Line Investment

Definition: Per-subscriber investment for hypothetical broadcast wireless loop systems, including customer premises equipment and per subscriber share of base station radios..

Default Value:

Wireless per Line Investment
$500

Support: Based on HAI judgment of potential cost of such a system.

2.11.5. Maximum Broadcast Lines per Common Investment

Definition: Hypothetical capacity of base station common equipment.

Default Value:

Wireless Broadcast Lines per Common Investment
30

Support: Based on HAI judgment of representative capacity of such a wireless broadcast system.

3. FEEDER INPUT PARAMETERS

3.1. COPPER PLACEMENT

3.1.1. Copper Feeder Structure Fractions

Definition: The relative amounts of different structure types supporting copper feeder cable in each density zone. Aerial feeder cable is attached to telephone poles, buried cable is laid directly in the earth, and underground cable runs through underground conduit. HM 5.0a may adjust the input values based on the buried fraction available for shift parameter using the process described in Section 2.5.2.

Default Values:

Copper Feeder Structure Fractions				
Density Zone	Aerial/Block Cable	Buried Cable	Underground Cable (calculated)	Buried Fraction Available for Shift*
0-5	.50	.45	.05	.75
5-100	.50	.45	.05	.75
100-200	.50	.45	.05	.75
200-650	.40	.40	.20	.75
650-850	.30	.30	.40	.75
850-2,550	.20	.20	.60	.75
2,550-5,000	.15	.10	.75	.75
5,000-10,000	.10	.05	.85	.75
10,000+	.05	.05	.90	.75

Note: Buried Fraction Available for Shift for Copper Feeder Structure Fractions is taken from the Buried Fraction Available for Shift for Fiber Feeder Structure Fractions.

Support: *{NOTE: Excerpts from the discussion in Section 2.5. [Distribution] are reproduced here for ease of use.}*

It is the opinion of outside plant engineering experts that density, measured in Access Lines per Square Mile, is a good determinant of structure type. That judgment is based on the fact that increasing density drives more placement in developed areas, and that as developed areas become more dense, placements will more likely occur under pavement conditions.

Aerial/Block Cable:

"The most common cable structure is still the pole line. Buried cable is now used wherever feasible, but pole lines remain an important structure in today's environment."[15]

Where an existing pole line is available, cable is normally placed on the existing poles. Abandoning an existing pole line in favor of buried plant is not usually done unless such buried plant provides a much less costly alternative.

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[15] Bellcore, *BOC Notes on the LEC Networks - 1994*, p. 12-41.

Buried Cable:

Default values in HM 5.0a reflect an increasing trend toward use of buried cable. Since 1980, there has been an increase in the use of buried cable for several reasons. First, before 1980, cables filled with water blocking compounds had not been perfected. Thus, prior to that time, buried cable was relatively expensive and unreliable. Second, reliable splice closures of the type required for buried facilities were not the norm. And third, the public now clearly desires more out-of-sight plant for both aesthetic and safety-related reasons.

Underground Cable:

Underground cable, conduit, and manholes are primarily used for feeder and interoffice transport cables, not for distribution cable. Any conduit runs short enough to not require a splicing chamber or manhole are classified to the aerial or buried cable account, respectively.

3.1.2. Copper Feeder Manhole Spacing, Feet

Definition: The distance, in feet, between manholes for copper feeder cable.

Default Values:

Copper Feeder Manhole Spacing, feet	
Density Zone	Distance between manholes, ft.
0-5	800
5-100	800
100-200	800
200-650	800
650-850	600
850-2,550	600
2,550-5,000	600
5,000-10,000	400
10,000+	400

Support: "The length of a conduit section is based on several factors, including the location of intersecting conduits and ancillary equipment such as repeaters or loading coils, the length of cable reels, pulling tension, and physical obstructions. Pulling tension is determined by the weight of the cable, the coefficient of friction, and the geometry of the duct run. Plastic conduit has a lower coefficient of friction than does concrete or fiberglass conduit and thus allows longer cable pulls. Conduit sections typically range from 350 to 700 ft in length."[16]

The higher density zones reflect reduced distances between manholes to provide transition points for changing types of sheaths and the increased number of branch points.

Maximum distances between manholes is also a function of the longest amount of cable that can be placed on a normal cable reel. Although larger reels are available, the common type 420 reel supports over 800 feet of 4200 pair cable[17], the largest used by the HAI Model. Therefore the longest distance between manholes used for copper cable is 800 feet.

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[16] Bellcore, *BOC Notes on the LEC Networks - 1994*, p. 12-42

[17] AT&T, *Outside Plant Engineering Handbook*, August 1994, pp. 1-7.

3.1.3. Copper Feeder Pole Spacing, Feet

Definition: Spacing between poles supporting aerial copper feeder cable.

Default Values:

Copper Feeder Pole Spacing	
Density Zone	Spacing, ft.
0-5	250
5-100	250
100-200	200
200-650	200
650-850	175
850-2,550	175
2,550-5,000	150
5,000-10,000	150
10,000+	150

Note: Whereas HM 5.0a assumes no distribution poles in the highest two density zones, there may be a few limited number of feeder poles to carry feeder cable in the high density urban zones.

Support: *{NOTE: The discussion in Section 2.6.2. [Distribution] is reproduced here for ease of use.}*

Distances between poles are longer in more rural areas for a several reasons. Poles are usually placed on property boundaries, and at each side of road intersections (unless cable is run below the road surface in conduit). Property boundaries tend to be farther apart in less dense areas, and road intersections are also farther apart.

Depending on the weight of the cable, and the generally accepted guideline that sag should not exceed 10 feet at mid-span, while still maintaining appropriate clearances as designated by the National Electric Safety Code, very long spans between poles may be achieved. This length may be as great as 1,500 feet using heavy gauge strand and very light cable, or may be shorter for heavier cables.[18] In practice, much shorter span distances are employed, usually 400 feet or less.

"...where conditions permit, open wire spans can approach 400 feet in length with practical assurance that the lines will withstand any combination of weather condition. Longer spans mean savings in construction costs and a net reduction in over-all plant investment, including fewer poles to buy, smaller quantity of pole hardware required, and less construction time. The use of long spans also means a reduction in maintenance expense."[19]

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[18] Bellcore, *Clearance for Aerial Cable and Guys in Light, Medium and Heavy Loading Areas, (BR 627-070-015), Issue 1,* 1987.
　　see also, Bellcore, *Clearances for Aerial Plant, (BR 918-117-090), Issue 5,* 1987.
　　see also, Bellcore, *Long Span Construction (BR 627-370-XXX),* date unk.

[19] Lee, Frank E., *Outside Plant, abc of the Telephone Series, Volume 4,* abc TeleTraining, Inc., Geneva, IL, 1987, p. 41.

3.1.4. Copper Feeder Pole Investment

Definition: The installed cost of a 40' Class 4 treated southern pine pole.
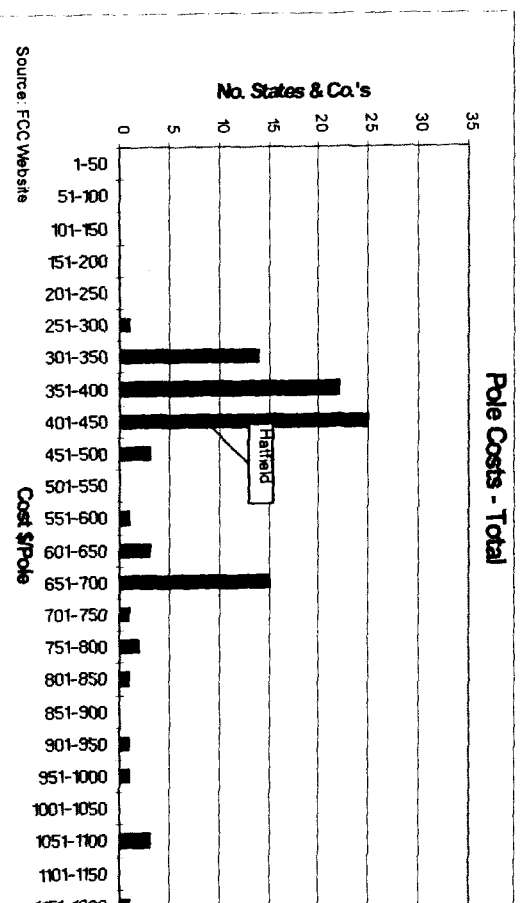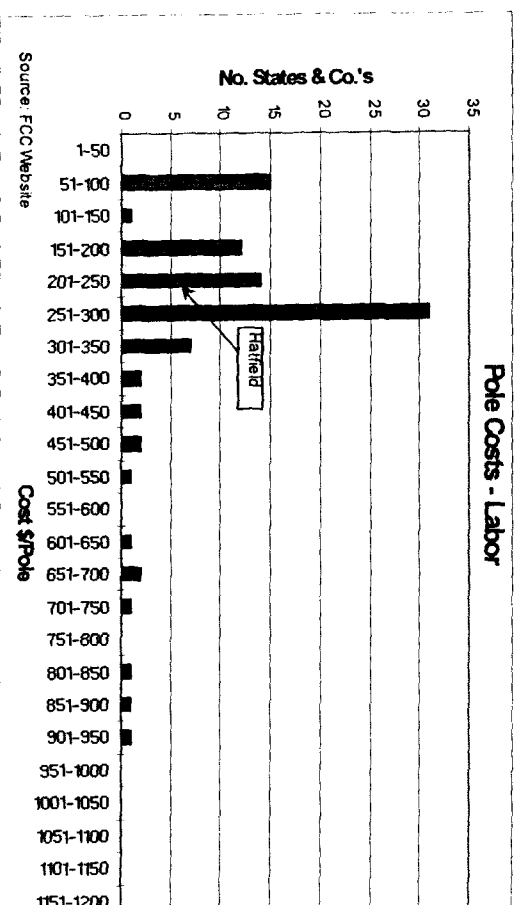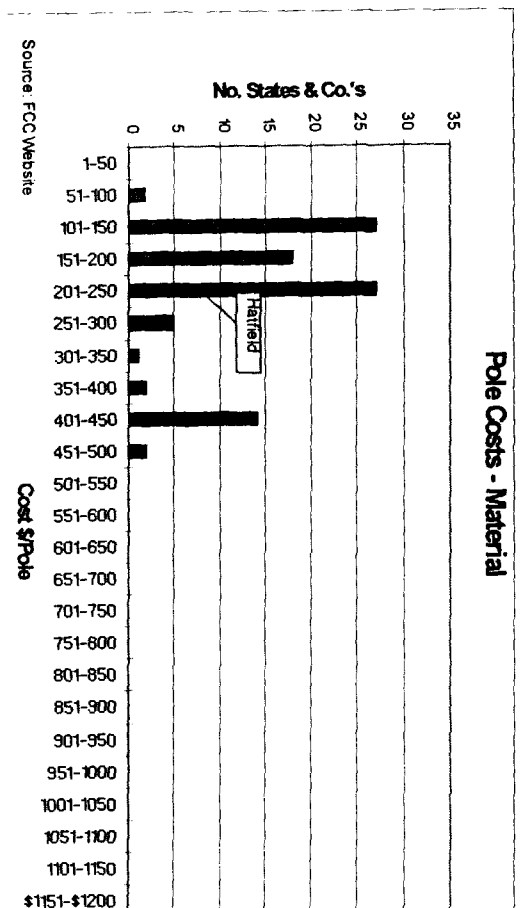
Default Values:

Pole Investment	
Materials	$201
Labor	$216
Total	$417

Support: *{NOTE: The discussion in Section 2.4.1. [Distribution] is reproduced here for ease of use.}*

Pole investment is a function of the material and labor costs of placing a pole. Costs include periodic down-guys and anchors. Utility poles can be purchased and installed by employees of ILECs, but are frequently placed by contractors. Several sources revealed the following information on prices.

Pole Investment
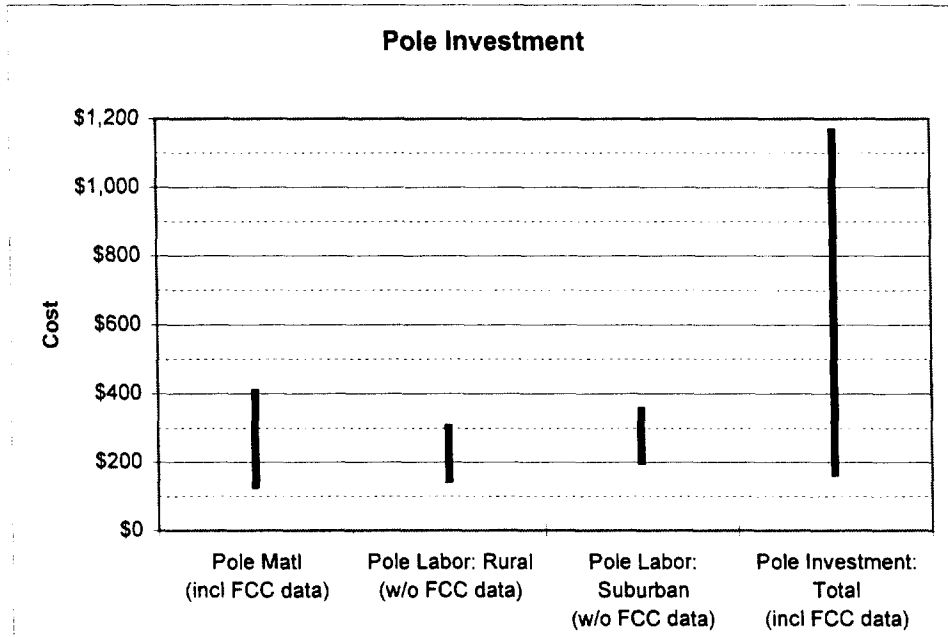
Pole data has also been recently filed by large telephone companies with the FCC. A compilation of that information is shown below:

Pole Costs - Material

No. States & Co.'s

Cost $/Pole

Hatfield

Source: FCC Website

Pole Costs - Labor

No. States & Co.'s

Cost $/Pole

Hatfield

Source: FCC Website

Pole Costs - Total

No. States & Co.'s

Cost $/Pole

Hatfield

Source: FCC Website

The exempt material load on direct labor includes ancillary material not considered by FCC Part 32 as a unit of plant. That includes items such as downguys and anchors that are already included in the pole placement labor cost. Outside plant engineering experts have concluded that a typical anchor plus anchor rod material investment is $45, and the typical guy material investment is $10. Also, one anchor and downguy per 1,000 feet would be typical. Therefore the embedded anchor and guy exempt material loading included in the default value of $216 is approximately $8.25 - $13.75 per pole.

The steel strand run between poles is likewise an exempt material item, charged to the aerial cable account. The cost of steel strand is not included in the cost of poles; it is included in the installed cost of aerial cable.

3.1.5. Innerduct Material Investment per Foot

Definition: Material cost per foot of innerduct.

Default Value:

Inner Duct Material Investment per foot
$0.30

Support:

Innerduct:
Innerduct might permit more than one fiber cable per 4" PVC conduit. The model adds investment whenever fiber overflow cables are required. This is a conservative assumption, since proper planning allows the placement of multiple fiber cables in a single 4" PVC without the use of innerduct.[20] Since HM 5.0a provides an additional spare 4" PVC conduit whenever fiber cable is run, additional innerduct is not required for a maintenance spare.

Outerduct:
Outerduct is similar to innerduct, but can be used in aerial or buried construction. Although commercially available, it is not recommended for use by outside plant engineering experts working with the HAI Model. Aerial outerduct should not be used in a forward looking model for several reasons. First, if outerduct is placed first, lashed to strand, and then fiber optic cable placed inside the outerduct later, this involves significant additional cost. At $0.30 per foot, outerduct becomes a significant cost compared to the relatively inexpensive fiber cable material cost. Second, it requires twice the cable placing effort – the innerduct must be placed and lashed, then a separate second operation is performed to pull fiber cable into the innerduct, and to secure it at each pole. Third, because of pulling resistance between the outerduct and the fiber optic cable, longer lengths of cable cannot be placed without unnecessary splicing, unless cable is pulled out of the outerduct, "figure-eighted" on the ground, and then reinserted into the outerduct for an additional distance. Fourth, although outerduct can be manufactured with the fiber optic cable inside, it serves little purpose and provides significant problems because the larger 1-1/2 inch outside diameter outerduct now has such a large diameter that only relatively short lengths can be spooled on a normal cable placing reel, compared to maximum placing lengths of 35,000 feet otherwise. Fifth, the use of outerduct in aerial applications presents a risk of "freeze outs", when water enters the innerduct, lays in low mid-span points and freezes, thereby expanding approximately 10% and exerting compression on the fiber cable.

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[20] *In fact, two outside plant engineering experts working with the HAI Model have had extensive experience is placing as many as 8 fiber cables in a single 4" PVC duct without innerduct.*

3.2. FIBER PLACEMENT

3.2.1. Fiber Feeder Structure Fractions

Definition: The relative amounts of different structure types supporting fiber feeder cable in each density zone. Aerial feeder cable is attached to telephone poles, buried cable is laid directly in the earth, and underground cable runs through underground conduit. HM 5.0a may adjust the input values based on the buried fraction available for shift parameter using the process described in Section 2.5.2.

Default Values:

Fiber Feeder Structure Fractions				
Density Zone	Aerial/Block Cable	Buried Cable	Underground Cable (calculated)	Buried Fraction Available for Shift
0-5	.35	.60	.05	.75
5-100	.35	.60	.05	.75
100-200	.35	.60	.05	.75
200-650	.30	.60	.10	.75
650-850	.30	.30	.40	.75
850-2,550	.20	.20	.60	.75
2,550-5,000	.15	.10	.75	.75
5,000-10,000	.10	.05	.85	.75
10,000+	.05	.05	.90	.75

Support: *{NOTE: Excerpts from the discussion in Section 2.5. [Distribution] are reproduced here for ease of use.}*

It is the opinion of outside plant engineering experts that density, measured in Access Lines per Square Mile, is a good determinant of structure type. That judgment is based on the fact that increasing density drives more placement in developed areas, and that as developed areas become more dense, placements will more likely occur under pavement conditions.

Aerial/Block Cable:

"The most common cable structure is still the pole line. Buried cable is now used wherever feasible, but pole lines remain an important structure in today's environment."[21]

Where an existing pole line is available, cable is normally placed on the existing poles. Abandoning an existing pole line in favor of buried plant is not usually done unless such buried plant provides a much less costly alternative.

Buried Cable:

Default values in HM 5.0a reflect an increasing trend toward use of buried cable. Since 1980, there has been an increase in the use of buried cable for several reasons. First, before 1980, cables filled with water

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[21] Bellcore, *BOC Notes on the LEC Networks - 1994*, p. 12-41.

blocking compounds had not been perfected. Thus, prior to that time, buried cable was relatively expensive and unreliable. Second, reliable splice closures of the type required for buried facilities were not the norm. And third, the public now clearly desires more out-of-sight plant for both aesthetic and safety-related reasons.

Underground Cable:

Underground cable, conduit, and manholes are primarily used for feeder and interoffice transport cables, not for distribution cable. Any conduit runs short enough to not require a splicing chamber or manhole are classified to the aerial or buried cable account, respectively.

Buried Fraction Available for Shift:

This input addresses the ability of the model to perform a dynamic calculation to determine the most efficient life-cycle costs of buried vs. aerial structure. The calculation considers the different values involved in buried vs. aerial structure in terms of initial investment, sub-surface conditions, soil texture, percent structure sharing, depreciation rates, and maintenance costs.

Underground conduit is not considered as a candidate for structure shifting, since the motivation for placing underground conduit and cable is usually a function of high pavement costs and the need to allow for future replacement and addition of cables without disturbing the above ground pavement conditions.

Since shifting of structure type from buried to aerial, or vice versa is permitted, the HAI Model allows the user to affect such shifting by the application of engineering judgment. There may be local ordinances or regulatory rules, that encourage utilities to place out-of-sight facilities under certain conditions. Therefore, should aerial structure be the most economic solution in a particular cable section, the model could shift all buried structure to aerial. However, in the event such shifting is not practical, the HAI Model allows the user to reserve a percentage of buried cable structure, regardless of the opportunity for a shift to less expensive aerial cable. Our outside plant engineering experts recommend that only 75% of the buried percentage be allowed to shift to aerial.

The user should note that this default value can be adjusted to 100% to allow the model to optimize the cable structure choice between aerial and buried structure without constraint.

3.2.2. Fiber Feeder Pullbox Spacing, Feet

Definition: The distance, in feet, between pullboxes for underground fiber feeder cable.

Default Values:

Fiber Feeder Pullbox Spacing, feet	
Density Zone	Distance between pullboxes, ft.
0-5	2,000
5-100	2,000
100-200	2,000
200-650	2,000
650-850	2,000
850-2,550	2,000
2,550-5,000	2,000
5,000-10,000	2,000
10,000+	2,000

Support: Unlike copper manhole spacing, the spacing for fiber pullboxes is based on the practice of coiling spare fiber (slack) within pullboxes to facilitate repair in the event the cable is cut or otherwise impacted. Fiber feeder pullbox spacing is not a function of the cable reel lengths, but rather a function of length of cable placed. The standard practice during the cable placement process is to provide for 5 percent excess cable to facilitate subsurface relocation, lessen potential damage from impact on cable, or provide for ease of cable splicing when cable is cut or damaged.[22] It is common practice for outside plant engineers to require approximately 2 slack boxes per mile.

3.2.3. Buried Fiber Sheath Addition, per Foot

Definition: The cost of dual sheathing for additional mechanical protection of buried fiber feeder cable.

Default Value:

Buried Fiber Sheath Addition, per foot
$0.20 / ft.

Support: Incremental cost for mechanical sheath protection on fiber optic cable is a constant per foot, rather than the ratio factor used for copper cable, because fiber sheath is approximately ½ inch in diameter, regardless of the number of fiber strands contained in the sheath. The incremental per foot cost was estimated by a team of experienced outside plant experts who have purchased millions of feet of fiber optic cable.

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[22] CommScope, *Cable Construction Manual*, 4th Edition, p. 75.

3.3. CABLE SIZING FACTORS

3.3.1. Copper Feeder Cable Sizing Factors

Definition: The factor by which feeder cable capacity is increased above the size needed to serve a given quantity of demand in order to provide spare pairs for breakage, line administration, and some amount of growth. Calculated as the ratio of the number of assigned pairs to the total number of available pairs in the cable.

Default Values:

Copper Feeder Cable Sizing Factors	
Density Zone	Factors
0-5	.65
5-100	.75
100-200	.80
200-650	.80
650-850	.80
850-2,550	.80
2,550-5,000	.80
5,000-10,000	.80
10,000+	.80

Support: *{NOTE: The discussion in Section 2.6.1. [Distribution] is reproduced here for ease of use.}*

In determining appropriate cable size, an outside plant engineer is more interested in a sufficient number of administrative spares than in the percent sizing ratio. The appropriate "target" feeder cable sizing factor, therefore, will vary depending upon the size of cable. For example, 75% utilization in a 2400 pair cable provides 600 spares. However, 50% utilization in a 6 pair cable provides only 3 spares. Since smaller cables are used in lower density zones, Distribution Cable Sizing Factors in HM 5.0a are lower in the lowest density zones to account for this effect.

In general, the level of spare capacity provided by default values in HM 5.0a is sufficient to meet current demand plus some amount of growth. Because the model calculates the unit loop investment cost as the total loop investment (including spare capacity), divided by the current loop demand, the resulting unit costs are a conservatively high estimate of the economic cost of meeting current loop demand. This occurs because, in reality, some of the spare copper feeder plant can and will be used to satisfy additional loop demand in the future, without causing any additional investment cost, thus a larger number of customers will pay for the cable over time. In this sense, the HM 5.0a default values for the copper feeder cable sizing factors are conservatively low from an economic costing standpoint.

3.3.2. Fiber Feeder Cable Sizing Factor

Definition: Percentage of fiber strands in a cable that is available to be used.

Default Values:

Fiber Feeder Cable Sizing Fill Factor	
Density Zone	Fill Factor
0-5	1.00
5-100	1.00
100-200	1.00
200-650	1.00
650-850	1.00
850-2,550	1.00
2,550-5,000	1.00
5,000-10,000	1.00
10,000+	1.00

Support: Standard fiber optic multiplexers operate on 4 fibers. One fiber each is assigned to primary optical transmit, primary optical receive, redundant optical transmit, and redundant optical receive. Since the fiber optic multiplexers used by HM 5.0a have 100 percent redundancy, and do not reuse fibers in the loop, there is no reason to divide the number of fibers needed by a cable sizing fill factor, prior to sizing the fiber cable to the next larger available size.

3.4. CABLE COSTS

3.4.1. Copper Feeder Cable: Cost per Foot, Cost per Pair-Foot

Definition: The cost per foot ($/foot) and per pair-foot of copper feeder cable, as a function of cable size, including the costs of engineering, installation, and delivery, as well as the cable material itself. The copper investment per pair-foot is used in estimating comparative life-cycle costs for copper feeder.

Default Values:

Copper Feeder Investment	
Cable Size	**$/foot (u/g & aerial)**
4200	$29.00
3600	$26.00
3000	$23.00
2400	$20.00
1800	$16.00
1200	$12.00
900	$10.00
600	$7.75
400	$6.00
200	$4.25
100	$2.50
Copper Investment per Pair - foot	
$ 0.0075 / pair-ft.	

Support: These costs reflect the use of 24-gauge copper feeder cable for cable sizes below 400 pairs, and 26-gauge copper feeder cable for cable sizes of 400 pairs and larger. Although 24-gauge copper is not required for transmission requirements within 18,000 feet of a digital central office with a 1,500 ohm limit, a heavier gauge of copper is used in smaller cable sizes to prevent damage from craft handling wires in pedestals where wires may be exposed, rather than sealed in splice cases. For cables of 400 pairs and larger, splices are normally enclosed in splice cases, and are not subject to wire handling problems.

Cable below 400 Pairs: Outside plant planning engineers commonly assume that the cost of cable material can be represented as an a + bx straight line graph. In fact, Bellcore Planning tools, EFRAP I, EFRAP II, and LEIS:PLAN have the engineer develop such an a + bx equation to represent the cost of cable. As technology, manufacturing methods, and competition have advanced, the price of cable has been reduced. While in the past, the cost of copper cable was typically ($0.50 + $0.01 per pair) per foot, current costs are typically ($0.30 + $0.007 per pair) per foot.

In the opinion of expert outside plant engineers, whose experience includes writing and administering hundreds of outside plant "estimate cases" (large undertakings), material represents approximately 40% of the total installed cost. This is a widely used rule of thumb among outside plant engineers. Such expert opinions were also used to determine that the average engineering content for installed copper cable is 15% of the installed cost. The remaining 45% represents direct labor for placing and splicing cable, exclusive of the cost of splicing block terminals into the cable.

Cable of 400 Pairs and Larger: As copper cable sizes become larger, engineering cost is based more and more on sheath feet, rather than cable size. The same is true for cable placing and splice set-up. Therefore the linear relationship between the number of copper pairs and installed cost is somewhat reduced. A

review of many installed cable costs around the country were used by the engineering team to estimate the installed cost of copper cable for sizes of 400 pairs and larger.

The following chart represents the default values used in the Model.

Copper Feeder Cable
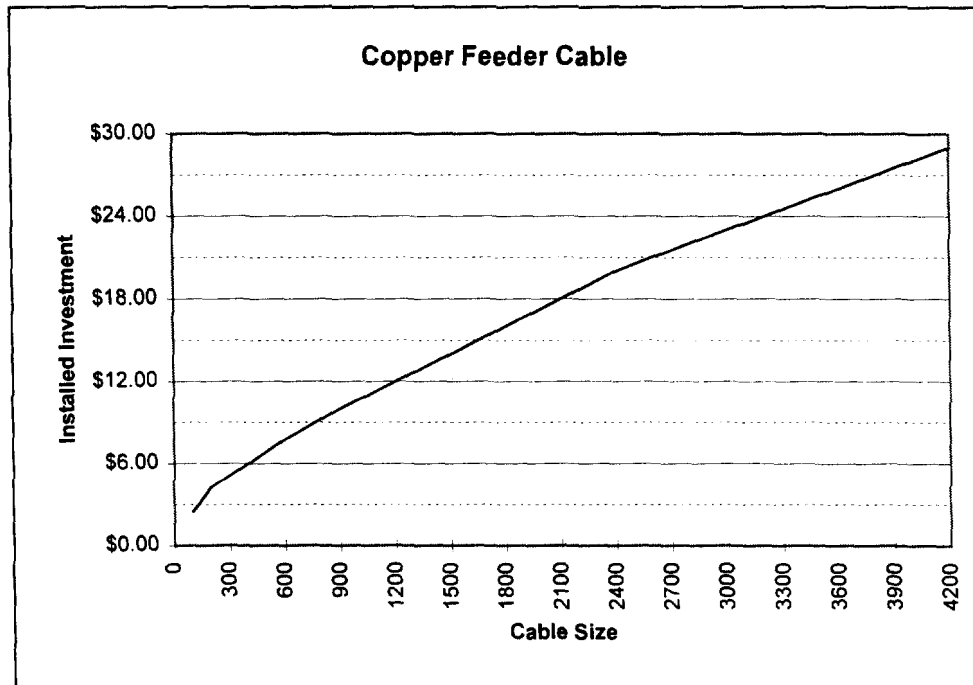
Copper Investment per Pair-Foot:
At the point in the model where a decision is required regarding copper vs. fiber feeder, it is not possible to determine how many copper pairs will be aggregated along each tapered section of the feeder route. Therefore a design assumption is required to determine how much of the fixed cost of the copper cable placement and sheath cost is distributed over the number of copper feeder pairs deployed. This is approximately $0.0075 per copper pair foot in the model.

3.4.2. Fiber Feeder Cable: Cost per Foot, Cost per Strand - Foot

Definition: The cost per foot ($/foot) and per strand-foot of fiber feeder cable, as a function of cable size, including the costs of engineering, installation, and delivery, as well as the cable material itself. The fiber investment per strand-foot is used in estimating comparative life-cycle costs for copper and fiber feeder.

Default Values:

Fiber Feeder Investment	
Cable Size	**$/foot (u/g & aerial)**
216	$13.10
144	$9.50
96	$7.10
72	$5.90
60	$5.30
48	$4.70
36	$4.10
24	$3.50
18	$3.20
12	$2.90
Fiber Investment per Strand - foot	
$ 0.10 / fiber-ft.	

Support: Outside plant planning engineers commonly assume that the cost of cable material can be represented as an a + bx straight line graph. In fact, Bellcore Planning tools, EFRAP I, EFRAP II, and LEIS:PLAN have the engineer develop such an a + bx equation to represent the cost of cable. As technology, manufacturing methods, and competition have advanced, the price of cable has been reduced. While in the past, the cost of fiber cable was typically ($0.50 + $0.10 per fiber) per foot, current costs are typically ($0.30 + $0.05 per fiber) per foot.

Splicing Engineering and Direct Labor are included in the cost of the Remote Terminal Installations, and the Central Office Installations, since field splicing is unnecessary with fiber cable pulls that are as long as 35,000 feet between splices.

Placing Engineering and Direct Labor are estimated at $2.00 per foot, consisting of $0.50 in engineering per foot, plus $1.50 direct labor per foot. These estimates were provided by a team of Outside Plant Engineering and Construction experts.

The following chart represents the default values used in the model.

Fiber Cable Installed Cost
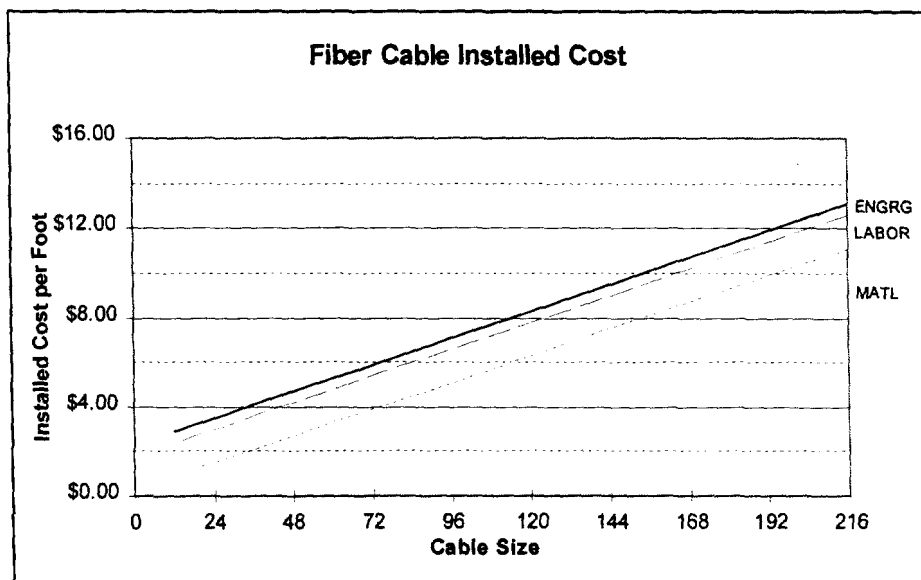
Fiber Investment per Strand – foot:

At the point in the model where a decision is required regarding copper vs. fiber feeder, it is not possible to determine how many fibers will be aggregated along each tapered section of the feeder route. Therefore a design assumption is required to determine how much of the fixed cost of the fiber cable placement and sheath cost is distributed over the number of fibers deployed. This is approximately $0.1000 per fiber strand foot in the model.

3.5. DLC EQUIPMENT

3.5.1. DLC Site and Power per Remote Terminal

Definition: The investment in site preparation and power for the remote terminal of a Digital Loop Carrier (DLC) system.

Default Values:

Remote Terminal Site and Power	
High Density GR-303 DLC	Low density GR-303 DLC
$3,000	$1,300

Support: The incremental per site cost was estimated by a team of outside plant experts with extensive experience in contracting for remote terminal site installations. Low Density DLC cabinets can be mounted on a small 41" x 38" prefabricated concrete or fiberglass pad.

3.5.2. Maximum Line Size per Remote Terminal

Definition: The maximum number of lines supported by the initial line module of a remote terminal.

Default Values:

Maximum Line Increment per Remote Terminal	
High Density GR-303 DLC	Low density GR-303 DLC
672	120

Support:

High Density Applications:
The forward looking DLC optimized for high density applications is an integrated NGDLC (Next Generation Digital Loop Carrier) compliant with Bellcore Generic Requirements GR-303, which employs an optical fiber SONET OC-3 transport capable of supporting 2016 full time DS0 POTS time slots. This is a large capacity and highly efficient digital loop carrier for serving the high density environment. While products from different vendors are available in a variety of sizes, HM 5.0a uses typical digital loop carrier remote sizes, which are as follows:

   672 DS0s   Modeled by HM 5.0a as an Initial Line Increment
   1344 DS0s   Modeled by HM 5.0a as an Initial Line Increment plus One Additional Increment
   2016 DS0s   Modeled by HM 5.0a as an Initial Line Increment plus Two Additional Increments

Low Density Applications:
Similar to the high density environment, there are a wide variety of DLC products available for low density applications. These DLC products are NFDLC and are also GR-303 compliant. HM 5.0a uses a 50 Mbps fiber optic based NGDLC that can be configured in a variety of ways (Point-to-Point, Drop and Insert, and Tree Configurations), both as an Integrated Digital Loop Carrier and as a "stand-alone" or Universal Digital Loop Carrier. HM 5.0a utilizes the IDLC configuration. This is a highly efficient digital loop carrier for low density applications. While a variety of sizes are available, the following sizes are used in HM 5.0a:
   120 DS0s   Modeled by HM 5.0a as an Initial Line Increment
   240 DS0s   Modeled by HM 5.0a as an Initial Line Increment plus One Additional Increment

3.5.3. Remote Terminal Sizing Factor

Definition: The line unit sizing factor in a DLC remote terminal, that is, the ratio of lines served by a DLC remote terminal to the number of line units equipped in the remote terminal.

Default Values:

Remote Terminal Fill Factors	
High Density GR-303 DLC	Low Density GR-303 DLC
.90	.90

Support: The most expensive part of integrated digital loop carrier provisioning is the digital to analog conversion that takes place in the Remote Terminal line card. This expensive card (HM5.0a defaults to $310 per 4 line card) calls for stringent inventory control on the part of the ILEC. Also, fill factors are largely a function of the time frame needed to provide incremental additions. Since line cards are a highly portable asset, facility relief can be provided by dispatching a technician with line cards, rather than engaging in a several month long copper cable feeder addition. Therefore high fill rates should be the norm for an efficient provider using forward looking technology.

3.5.4. DLC Initial Common Equipment Investment

Definition: The installed cost of all common equipment and housing in the remote terminal, as well as the fiber optics multiplexer required at the CO end, for the initial line module of the DLC system (assumes integrated digital loop carrier (IDLC) with a GR-303 interface to the local digital switch).

Default Values:

Remote Terminal Initial Common Equipment Investment	
High Density GR-303 DLC	Low Density GR-303 DLC
$66,000	$16,000

Support: The cost of an initial increment of Integrated Digital Loop Electronics was estimated by a team of experienced outside plant experts with extensive experience in contracting for remote terminal site installations. Low Density DLC material investments are based on vendor list prices and an estimated 25 percent discount based on large volume purchases.

3.5.5. DLC Channel Unit Investment

Definition: The investment in channel units required in the remote terminal of the DLC system.

Default Values:

GR-303 and low density DLC channel unit investment per unit				
	POTS Channel Unit		Coin Channel Unit	
DLC Type	Channel Card	No. Lines	Channel Card	No. Lines
High Density GR-303	$310	4	$250	2
Low Density GR-303	$600	6	$600	6

Support: The cost of individual POTS Channel Unit Cards was estimated by a team of experienced outside plant experts with extensive experience in contracting for DLC channel units. For the Low Density DLC, the cost is based on vendor list prices and an estimated 25 percent discount based on large volume purchases.

3.5.6. DLC Lines per Channel Unit

Definition: The number of lines that can be supported on a single DLC channel unit.

Default Values:

Lines per Channel Unit		
	POTS Channel Unit	Coin Channel Unit
DLC Type	No. Lines	No. Lines
High Density GR-303	4	2
Low Density GR-303	6	6

Support: This is based on vendor documentation.

3.5.7. Low Density DLC to GR-303 DLC Cutover

Definition: The threshold number of lines served, above which the GR-303 DLC will be used.

Default Value:

Low Density GR-303 DLC to High Density GR-303 DLC Cutover
480 lines

Support: An analysis of initial costs reveals that 2 Low Density DLC units, at 240 lines each, are more cost effective than a single large IDLC unit with a capacity of 672 lines. Beyond two 240 line Low Density DLC units, the larger unit is less costly.

3.5.8. Fiber Strands per Remote Terminal

Definition: The number of fibers connected to each DLC remote terminal.

Default Values:

Fibers per Remote Terminal	
High Density GR-303 DLC	Low density GR-303 DLC
4	4

Support: HM 5.0a assumes a configuration with two main fibers (one for transmit and one for receive) and two protection fibers (one for transmit and one for receive). The protection fibers are equipped and provide transmission redundancy for improved service reliability. The number of fibers required is based on vendor documentation.

3.5.9. Optical Patch Panel

Definition: The investment required for each optical patch panel associated with a DLC remote terminal.

Default Values:

Optical Patch Panel	
High Density GR-303 DLC	Low density GR-303 DLC
$1,000	$1,000

Support: The cost for an installed fiber optic patch panel, including splicing of the fibers to pigtails, was estimated by a team of experienced outside plant experts with extensive experience in contracting for optical patch panels. A fiber optic patch panel contains no electronic, nor moving parts, but allows for the physical cross connection of fiber pigtails.

3.5.10. Copper Feeder Maximum Distance, Feet

Definition: The feeder length above which fiber feeder cable is used in lieu of copper cable. The value must be less than 18,000 feet.

Default Value:

Copper Feeder Maximum Distance
9,000 feet

Support: The chart below depicts the result of multiple sensitivity runs of the HAI Model, wherein the only variable changed is the copper/fiber maximum distance point. Results indicate that Loop Costs per month drop off as the fiber/copper cross-over distance is increased. This reduction in monthly costs is a function of the investment and maintenance carrying charges for the loop. There is a significant slope from an all fiber feeder at 0 kft. down to 9,000 feet, where the slope becomes essentially flat.

HM 5.0a uses several parameters to determine the need for fiber feeder cable, rather than copper feeder cable. These include 1) assuring that the total copper cable length for both copper feeder and copper distribution do not exceed the threshold value set by default at 18,000 feet; 2)assuring that the copper distribution distance alone does not exceed the threshold value set by default at 18,000 feet; 3) assuring that copper feeder cable does not exceed the Copper Feeder Maximum Distance set by default here at 9,000 feet; and lastly, HM 5.0a tests to see if copper feeder is called for after examining the 3 tests above, whether fiber feeder would have a lower life-cycle cost than copper feeder based on annual carrying